한국환경과학회 봄학술발표회 발표논문집 제12권(제1호), 363 - 367, 2003
Proceedings of the Korean Environmental Sciences Society Conference, May. 16~17, 2003

OC2

Sediment yield model coupling runoff model

Young-Hwa Lee
Department of Civil Engineering, Kyungsan University

Introduction

Estimates of watershed sediment yield are required for design of dams and reservoirs, soil conservation practices, and debris basins; determination of pollutants; depletion of reservoirs, lakes and wetlands; determination of the effects of basin management; and cost evaluation. Increased awareness of environmental quality and the desire to control non-point source pollution have significantly increased the need for sediment yield estimates, for sediment is a pollutant or a carrier of pollutants, such as radioactive material, pesticides, and nutrients.

Rendon-Herrero (1974, 1978) derived a unit sediment graph (USG) and Williams (1978) derived the instantaneous unit sediment graph (IUSG). The concept of IUSG was also employed by Singh et al. (1982), Chen and Kuo (1984), and Srivastava et al. (1984) among others. Lee and Singh (1999) analyzed sediment yield by coupling Kalman filter with the IUSG.

The objective of this study is to develop a tank model for prediction of runoff and sediment yield, test it on an upland watershed in northwestern Mississippi, and compare it with the IUSG model.

Tank model for sediment yield

For determining the sediment yield by the tank model, the initial sediment concentration distribution (ISCD) of the first tank is produced by the incremental source runoff (or the effective rainfall) and sediment concentration of the next lower tank is computed from the sediment infiltration of the upper tank. The sediment concentration of the first tank is computed from its storage and the ISCD; the sediment concentration of the next lower tank is obtained by its storage and the sediment infiltration of the upper tank; and so on. The sediment yield through the side outlet is obtained by multiplying the total sediment yield, obtained by the product of runoff and the sediment concentration, by the sediment yield coefficient. The sediment infiltration through the bottom outlet is obtained by multiplying the total sediment infiltration, obtained by the product of infiltration and the sediment concentration, by the sediment infiltration coefficient.

Initial Sediment Concentration Distribution

The initial sediment concentration distribution (ISCD) caused by rainfall was estimated by considering the sediment-routing equation (Williams, 1975b).

The ISCD used in the tank model can be expressed as

$$C_{0i} = \frac{Yv_i}{[H \sum_{j=1}^{m} v_j^2]} \tag{1}$$

To use (10) v_i, Y, H must be determined. v_i is the incremental source runoff at time i. Y was predicted with the modified universal soil loss equation, MUSLE (Williams, 1975 a):

$$Y = 11.8(V_Q q_p)^{0.56} KCP(LS) \tag{2}$$

In which V_Q is the volume of runoff, q_p is the peak flow rate, K is the soil factor, C is the crop management factor, P is the erosion control practice factor, and LS is the slope length and gradient factor.

$$H = \int_0^{\infty} h(w) \exp(-awd^{0.5}) dw \tag{3}$$

where H is the IUSG, $h(w)$ is the IUH ordinate, a is the routing coefficient, w is the travel time between the two sections, and d is the median sediment particle diameter.

Application and analysis

Study basin

A small upland watershed, W-5, a part of the Pigeon Roost basin located near Oxford in Marshall County, Mississippi, was selected for testing the tank model. The watershed has an area of approximately 4.04 ㎢, is 1288m long and 128.8m wide. The watershed consists of a rather flat flood plain with natural channels and rolling, severely dissected interfluvial areas. The channels have a few straight reaches, and most have banks that scour easily. The average channel width-depth ratio is approximately 2:1 at the gaging station. A detailed description of this watershed is given by Bowie and Bolton (1972).

Model parameters

The parameters were estimated by trial and error by minimizing the error between observed and computed runoff and sediment yields and given in Table 1.

Table 1. Parameters of the tank model

Storm	A1	A2	A3	B1	C1	A0	B0	C0	HA1	HA2	HA3	HB	HC
No.1(72.12.9)	.09	.09	.09	.05	.01	.09	.05	.01	8	4	1	1	1
No.2(73.3.14)	.07	.07	.07	.02	.005	.07	.02	.005	8	4	1	1	1
No.3(75.1.10)	.10	.10	.10	.05	.01	.01	.05	.01	8	4	1	1	1
No.4(75.3.12)	.08	.08	.08	.05	.01	.08	.05	.01	8	4	1	1	1
Mean	.085	.085	.085	.043	.009	.063	.043	.009	8	4	1	1	1

Initial Sediment Concentration Distribution

The ISCD was determined from (1) and the IUH was determined by the Nash model for each event. The parameters for the sediment yield estimated by MUSLE in (2) for watershed W-5 are as follows: The soils factor, K, is 0.26, the crop management factor, C, is 0.07, the erosion control practice factor, P, is 0.47 and the slope length and gradient factor, LS, is 0.34. The routing coefficient a, for estimating H is given in Table 2. The initial concentration for one unit of runoff, C0, the sediment yield, Y, estimated by MUSLE and H in (1) for each event are given in Table 2. The ISCD was estimated by multiplying C_0 by the incremental source runoff.

Table 2. Characteristic values for the determination of the ISCD

storm	a	H	C_0 (mg/l)	Y (t/h)
No.1	0.256	1596.27	195595.1	91.30
No.2	1.735	577.88	257880.3	110.08
No.3	0.592	888.48	245075.4	62.83
N0.4	0.837	697.05	210107.8	70.75

Determination of Runoff hydrograph

The runoff hydrograph was computed for each event by the tank model.

The calculated error indices for the hydrograph by the tank model are given in Table 3. The model efficiencies for each event were between 0.67 and 0.80.

Table 3. Error indices for the hydrograph by the tank model

Storm	ME	MSE	Bias	VER(%)	PER(%)	TER(min)
No.1	0.80	2.08	1.03	18.48	16.74	15
No.2	0.75	3.31	0.91	16.92	-17.24	5
No.3	0.76	2.39	1.46	26.57	4.81	15
No.4	0.67	2.80	1.34	25.76	-30.04	5

Determination of Sediment yield

The sediment yield was computed for each event by the tank model. The sediment yield was also computed by the IUSG and compared with the sediment yield computed by the tank model. These error indices for the sediment yield by the tank model and IUSG are given in Table 4. As shown in the table, the model efficiencies for each event are shown between 0.80 and 0.90 for tank model and between 0.69 and 0.75 for IUSG. The above results show that the tank model is a suitable model for computing sediment yield.

Table 4. Error indices for the sediment yield by the tank model and IUSG

Storm	ME		MSE		Bias		VER(%)		PER(%)		TER(min)	
	Tank	IUSG	Tank	IUSG	Tank	IUSG	tank	IUSG	Tank	IUSG	Tank	IUSG
No.1	0.80	0.69	30.69	51.17	10.16	31.16	15.36	37.10	5.47	39.87	10	15
No.2	0.90	0.71	83.47	143.8	39.53	62.33	20.06	31.64	1.03	20.49	10	20
No.3	0.85	0.70	50.22	97.12	20.87	44.06	20.22	30.68	20.55	46.20	5	-5
No.4	0.83	0.75	56.18	83.71	-4.47	22.99	-5.15	26.48	-2.28	39.68	5	-5

Conclusions

The following conclusions can be drawn from this study. (1) The tank model satisfactorily simulated runoff and sediment yield. (2) The sediment yield computed by the tank model was in good agreement with the observed sediment yield and was more accurate than the sediment yield computed by the IUSG model. (3) The sediment yield graphs have approximately the same shapes as do the runoff hydrographs. (4) The values of the coefficients used for computing runoff and sediment yield by the tank model are the same. This makes model easy to apply.

References

Lee Y. H and Singh, V. P., 1999. 'Prediction of sediment yield by coupling Kalman filter with instantaneous unit sediment graph,' Hydrological Processes, 2861-2875.

Nash, J. E. 1960. 'A unit hydrograph study with particular reference to British catchments,' Proceeding of the Institution of Civil Engineers (London)17, 249-282.

Singh, V. P. and Baniukiwicz, A. and Chen V. J., 1982. 'An instantaneous unit sediment graph study for small upland watersheds,' Littieton, Colo. : Water Resources Publications.

Sugawara, M., Watanabe, I., Ozaki, E. and Katsuyama, Y., 1984. 'Tank model with snow component,' Research Notes, No.65, National research Center for Disaster Prevention, Japan.

Williams, J. R., 1975b. 'Sediment routing for agriculture watersheds,' Water Resources Bulletin 11(5), 965-74.

Williams, J. R., 1978b. 'A sediment graph model based on an instantaneous unit sediment graph,' Water Resources Research 14(4), 659-64.